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DESIGN AND ANALYSIS OF CRACK PROPAGATION ON OFFSHORE JACKET PLATFORM UNDER GRAVITY AND ENVIRONMENTAL LOAD

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ABSTRACT

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This research involves the design, calculation and analysis of crack length of an offshore jacket platform and the simulation to determine the safety of the platform with given material properties and diameters. From the calculation, a model of the platform was developed with Ansys software. The simulation was ran with certain loads such as gravity load, wind force and wave force to ensure its efficiency to withstand the given loads and to establish the safety of the platform. During the simulation, cracks were observed on the T-joint, and welded joint between the chord and the brace. This type of crack is mostly instigated by the presence of residual stress and the rigidity of the joint, as a result of the metal inability to expand or contract. It was also established, the variance between the calculated crack length and the simulated crack length, its location, type of crack and the safety of the platform. A calculated crack length of 0.129inch and $4.4 * 10^4\ Cycles$ to failure was achieved while a simulated crack length of 0.133inch was also established, which is located at the T-joint, the weld between the chord and the brace, a semi-elliptical crack. However, both the calculated crack length and the simulated crack length are approximately the same value. Thus; the platform is safe and it will take $4.4 * 10^4\ Cycles$ for the crack to propagate. Thereafter, measures to mitigate the propagation of crack must be considered.

KEYWORDS: Crack, Gravity, Load, Crack, Offshore, Ansys, Platform.

1.0 INTRODUCTION

This research is focused on crack in offshore structure, basically in the steel jacket tubular joints. How cracks developed in offshore structures, when crack growth occurs, speed and direction of crack, and how to stop the growth. This work is limited to the methods or approach to analyzing Cracks in offshore steel jacket platform.

The offshore industry is mainly a working environment set up with multiples of metallic or steel structures which carries a great amount of both static and dynamic loads, as well as prone to environmental factors, such as salt water, waves of different forces and winds which influence the corrosion of steel materials and the integrity of these offshore structures. For this reason, offshore materials and platforms undergo periodic maintenance, among other safety inspection and application. Among the frequently observed is the crack of steel materials which may vary according to size, motion, visibility and time. An intervention in determining solution to such anticipated occurrences requires a substantial amount of knowledge of fracture mechanics which will provide methods necessary in the approach for determining offshore structure integrity.

There are lots of provisions that require mathematical calculations in identifying such loads generating cracks in offshore structures, as well as theoretical applications that are more like a guideline or standards on what need to be done from the time in which offshore structures are being erected.

In this research, attentions were on cracks in steel jacket tubular joints as well as stress and crack analysis, as it is the main causes of fracture leading to crack propagation.

2.0 LITERATURE REVIEW

Offshore jacket platforms are mostly constructed as truss framework with welded tubular member as structural elements and have been extensively employed in the offshore oil and gas exploration in complicated ocean environments. The surrounding ocean environment is affected by various environmental loads such as the wind, wave, currents and ice. Out of the environmental loads, wave loads, which are cyclic in nature, causes very high stress concentrations especially at critical locations like the welded tubular joints, which leads to significant fatigue damage of the structure. In addition, jacket platforms are subjected to other types of loads, including severe storms, corrosion, fire, explosions, etc., during their service life. As structures reach their design service lives, the fatigue life should be reassessed. (Rohith et al., 2017).

Amaziah (2011) illustrates how the principal Environmental loads (wind and wave), current forces, loads from ice and loads from earth-quake (earth-quake prone zones) are deployed to archive the design and construction of offshore concrete gravity platforms. Two design methods (Analysis and Design of Shell structures) and the Tangent Modulus Methods of design of Offshore Concrete Gravity platforms. One of the most important reasons of fracture in jacket platforms that makes the suddenly

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failure and structural resistance reduce at long time is Fatigue phenomena. Sajed et al., (2017). Fatigue has long been recognized as an important consideration for designing offshore structures and intensive cooperative industry research on tubular joints. (A, Khalifa et al.,2014). António (2018), presented a wide analysis on the main contributing factor of fatigue for offshore structures as well as fatigue damage analysis possible of conducing crack propagation.

Mohammad et al., (2013) investigated the strength of marine structures. The structure is subjected to a maximum static load. However, the marine structures are usually suffering environmental forces varying with time. Wave forces are the most important time dependent loading that causes fatigue in structural elements and joints.

Kabir et al., (2019) emphasized on the types of platform, platform parts, platform installation, corrosion protection, platform foundation, naval architecture, structural design, structural analysis, acceptance criteria, and structural design and different codes. António (2018) also discussed the influence environmental actions have in an offshore structure and the strict dependency with the wave theory.

Most offshore Jacket platforms are installed in shallow water, less than 300 meters for drilling and production of oil or gas. They are normally fixed to seabed and constructed as three dimensional frameworks with tubular members as structural elements. The surrounding environment around offshore platform is affected by various environmental loads that comprise of wind, waves, currents and earthquake. The major load in such structures is wave loading, repetitive in nature which causes time varying stresses that results global and or local fatigue damage on the offshore steel structure. (Swethim et al.,2018).

However, the combination of gravity and environmental load rapidly contribute to crack propagation on offshore jacket platform.

3.0 MATERIALS AND METHOD

To effectively design and evaluate crack propagation on offshore jacket platform under gravity and
environmental load, the under listed were deliberated.

Review of existing literature.

Design concept development.

Selection of design concept.

Design calculations.

Design and simulation of the selected concept using Ansys software.

Crack propagation analysis due to gravity and environmental load.

3.1 Design calculation: crack length.

Considering structural steel in this analysis, with the following material properties:

Young's modulus $= \mathbf{2 * 10^{11} P_a}$, Poisson's ratio = 0.3, Density= $\mathbf{7850Kg * m^{-3}}$, Temperature= $\mathbf{22^{O}C}$, Tensile Yield

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Strength= $\boldsymbol{36259\,Psi}$, and an ultimate Strength= $\boldsymbol{66717\,Psi}$

An offshore platform will be presented with its joints, however, a T- joint is where the crack will be generated and will also be used to test the safety of the platform after a certain load have being applied.

Values for calculation

$C = 5.7{*}10^{-11}$

$a_f = 0.12$ inch

$a_i = 0.006$ inch

β= 1.15

$\sigma_{max} = 98$ inch

$K_1 = 72$ inch

n= 3

$$K_{max} = \sigma_{max} * \beta * \sqrt{\pi * a} \qquad (1)$$

$$K_{min} = \sigma_{min} * \beta * \sqrt{\pi * a} \qquad (2)$$

$$\Delta K = K_{max} - K_{min} = \Delta\sigma * \beta * \sqrt{\pi * a} \qquad (3)$$

A compressive stress is generated from crack closing; however, in order to generate a crack growth, a threshold is needed.

$$\Delta K_{th} = K_{op} - K_{min} \qquad (4)$$

Using the stress intensity factor-mode 1 to determine the crack length.

$$K_1 = \beta * \sigma * \sqrt{\pi * a} \qquad (5)$$

$$K_1^2 = \beta^2 * \sigma^2 * \pi * a$$

$$a = \frac{K_1^2}{(\beta * \sigma)^2 * \pi} \qquad (6)$$

If $\Delta K > \Delta K_{th}$ crack grows every circle.

$\frac{da}{dN}$ Depends on part that exceeds K_{op}

$a^{\uparrow}$ Crack length increase

$\Delta K^{\uparrow}$ Function of crack length

As the crack length $a^{\uparrow}$ increase, so as $\Delta K^{\uparrow}$ increase because $\Delta K$is a function of crack length.

Even if the load is constant, as $\frac{da}{dN}$ increase, ΔK is also increasing.

$\frac{da}{dN}$ Varies with ΔK (Relationship between $\frac{da}{dN}$ and ΔK)

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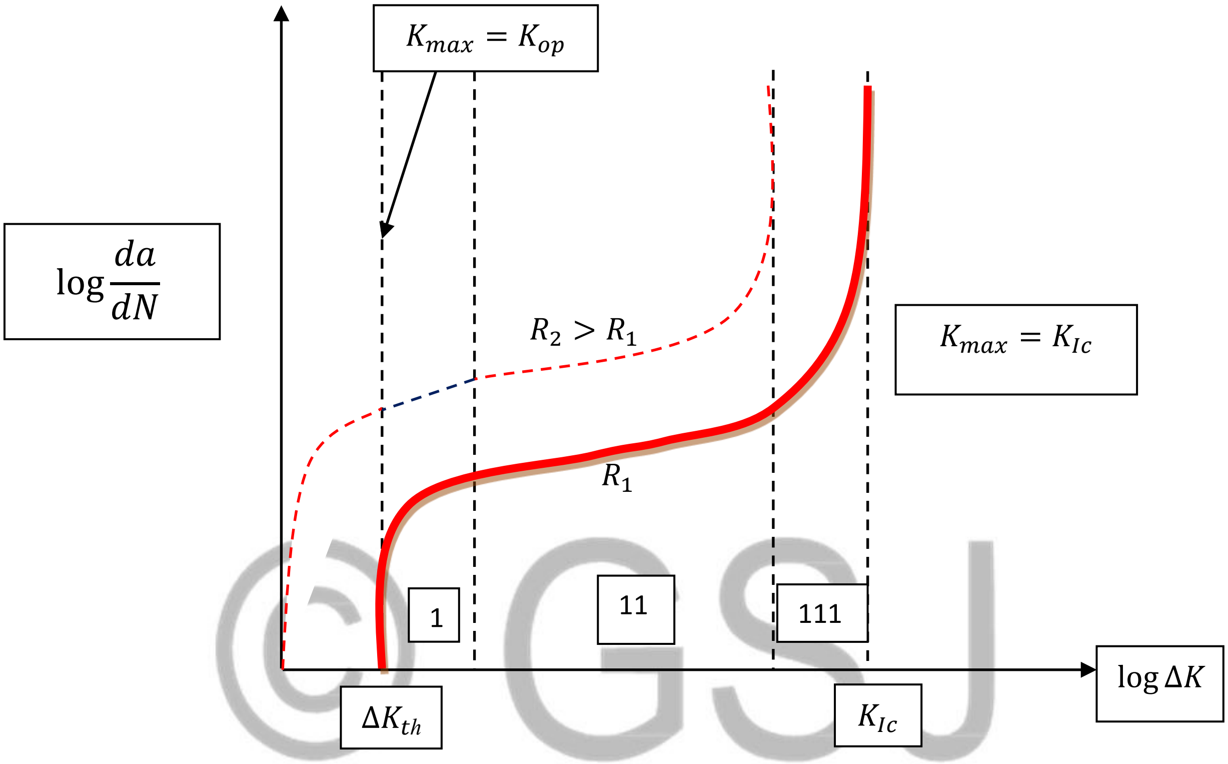

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Fig.1 Fatigue crack initiation and propagation

$\log \frac{da}{dN}$	Crack rate
$\log \Delta K$	Stress intensity factor
K_{max}	Maximum stress intensity factor
K_{Ic}	Fracture toughness of the material
ΔK_{th}	Crack growth start

$$R = \frac{\sigma_{min}}{\sigma_{max}} = \text{stress ratio}$$

When the crack growth is in mode (11), we have the formula

$$\frac{da}{dN} = C * \Delta K^{n}$$

In order to determine the number of cycles to failure (from equ.7)

$$\frac{da}{dN} = C * \Delta K^{n}$$

$$\frac{da}{dN} = C\,[\,\beta * \Delta\sigma * \sqrt{\pi * a}\,]^{n}$$

$$N_f = \int_{a_i}^{a_f} [\frac{1}{C\,[\,\beta * \Delta\sigma * \sqrt{\pi * a}\,]^{n}}]$$

$$N_f = \frac{1}{C * \Delta\sigma^{n}} \int_{a_i}^{a_f} (\beta * (\pi * a)^{\frac{1}{2}})^{-n}$$

$$N_f = [\frac{1}{\Delta\sigma * \sqrt{a} * \beta}]^{n} * \frac{2}{2-n} \left[a_f^{\frac{2-n}{2}} - a_i^{\frac{2-n}{2}} \right]$$

To calculate the crack length using eqn 6.

$$a = \frac{{K_1}^{2}}{\beta^{2} * \sigma^{2} * \pi}$$

$$a = \frac{{K_1}^{2}}{(\beta * \sigma)^{2} * \pi}$$

$a = \frac{72^{2}}{(1.15*98)^{2}*\pi}$ = 0.129 inch

a =0.129 inch * 25.4 $^{mm}/_{inch}$ = 3.3mm

Calculate Number of Cycles to failure (equ.8)

$$N_f = \frac{1}{5.7 * 10^{-11}} [\frac{1}{98 * \sqrt{\pi * 1.15}}]^{3} * \frac{2}{2-3} [(0.12)^{\frac{2-3}{2}} - (0.006)^{\frac{2-3}{2}}$$

$$N_f = 2201.20 = 4.4 * 10^{4}$$

$$N_f = 4.4 * 10^{4}\ Cycles$$

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3.2 ANSYS SIMULATION OF THE STEEL JACKET OFFSHORE PLATFORM

Ansys software is use for simulation of different models. It is used to create 3 and 2dimentional objects. In this case, a steel jacket platform was created and simulated in order to obtain the desired result by finding the crack length of the offshore jacket platform at a constant amplitude load.

3.2a GEOMETRY

The geometry is the first stage of Ansys simulation program to create or design any type of object of choice in the workbench.

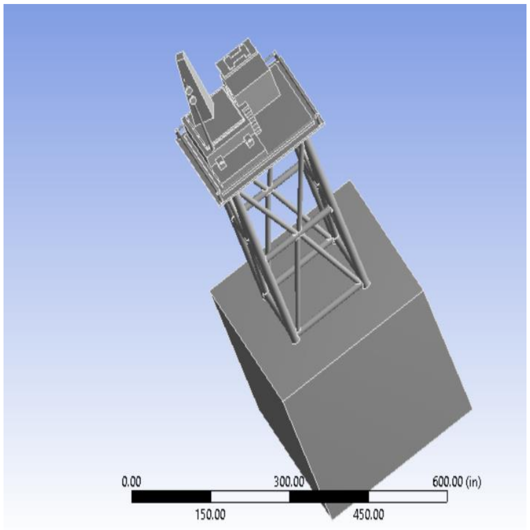

Fig.2a Geometry of the Offshore Structure

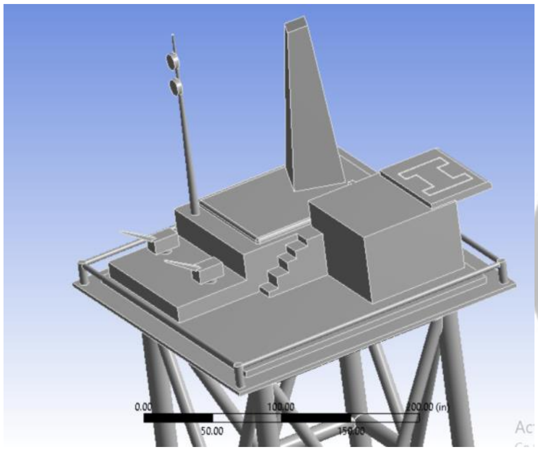

Fig.2b Geometry of the Offshore Structure

3.3 MESHING

After the geometry, the second stage of the Ansys is the Mesh. However, the mesh is one of the most important parts in ANSYS. In the Ansys simulation program, a model cannot be simulated without meshing.

Meshing is discretization of tetrahedral in 3D and discretization divides the created model into elements which consist of nodes (grids). The automatic mesh can choose the element size base on the local curvature. If there is no meshing, there will be no finite elements.

Sometimes, we set the meshing size in order to get the desired elements because when the meshing size is too high, the time that it will take to compute will increase as the complexity is going to be increase and the elements also will be increase.

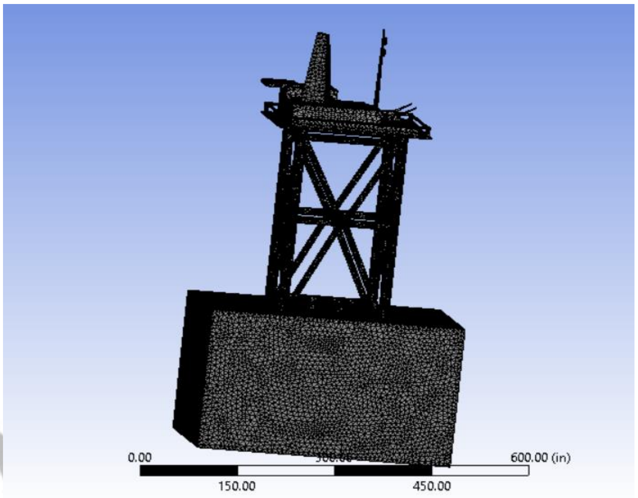

Fig.2 Mesh detail view.

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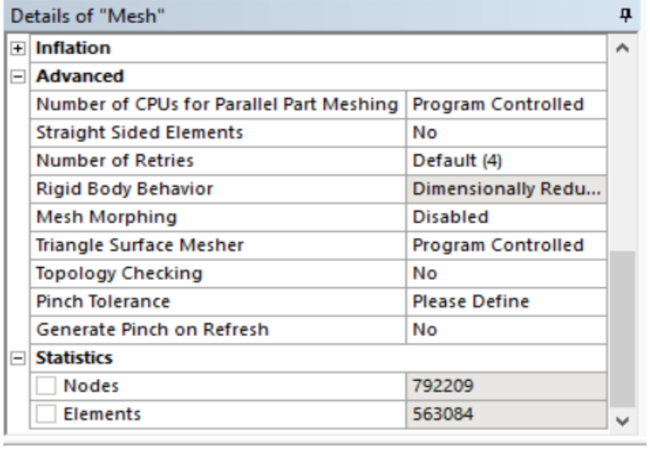
Table 1. Details for mashing.



Details of "Mesh"	
⊞ **Inflation**	
⊟ **Advanced**	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Redu...
Mesh Morphing	Disabled
Triangle Surface Mesher	Program Controlled
Topology Checking	No
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
⊟ **Statistics**	
☐ Nodes	792209
☐ Elements	563084

3.4a FORCES ACTING ON THE PLATFORM

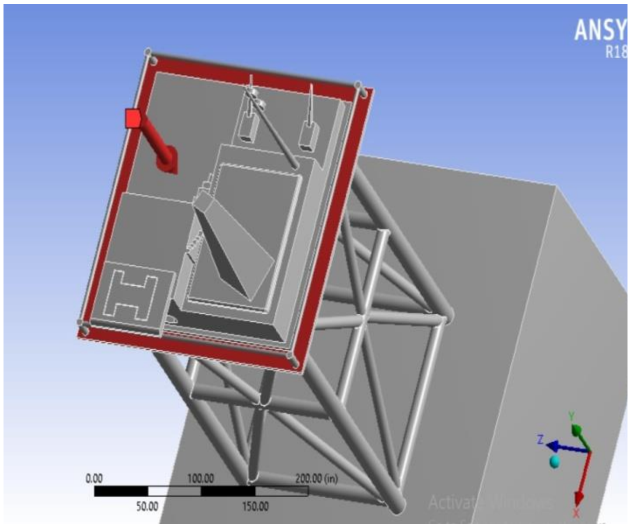


Fig.3 The gravity load.

3.4b Red arrow represents the gravity force of the tower with the drilling mechanism

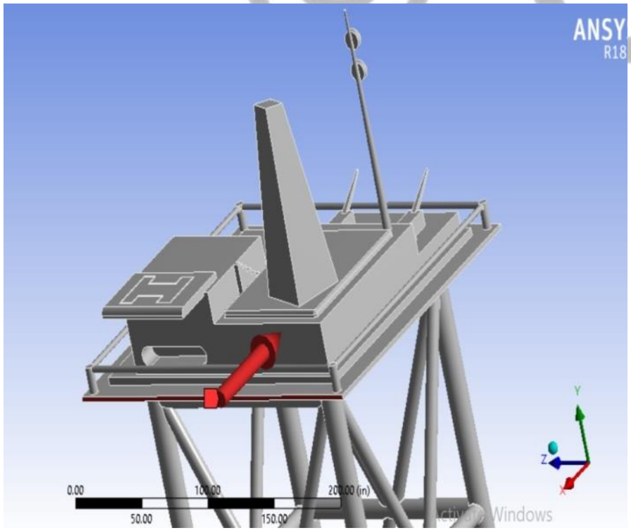


Fig.4 Wind force

3.4c Red point specified in the above picture, will be detailed below.

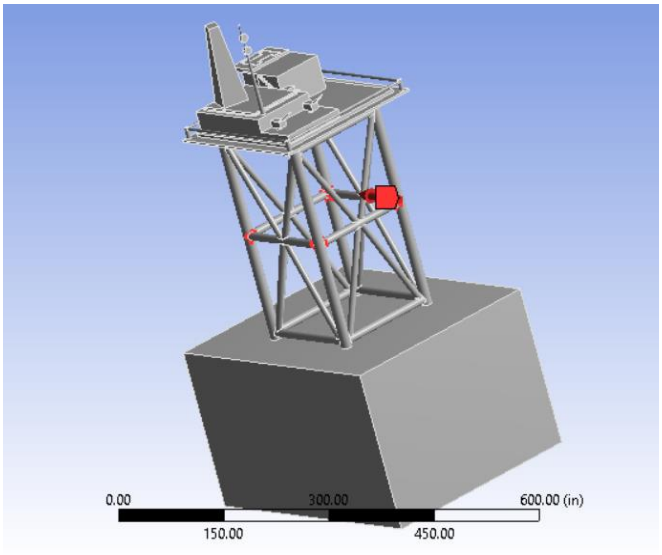


Fig.5 Wave force acting on the pillars.

Also, we consider in this k-joint on seam weld the concentration force from the waves **(Fig. 3.5).**

The principal stress acting in this point will be presenting in the **3.4, below**.

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3.4 VECTOR PRINCIPAL STRESS

The vector principal stress helps to understand the direction or part of the model that experiences the greatest amount of stress hence the maximum, middle and minimum principal.

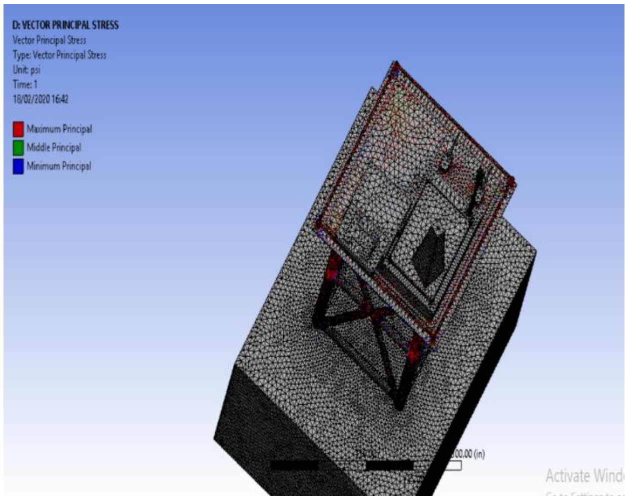

Fig. 6a The Vector Principal stress

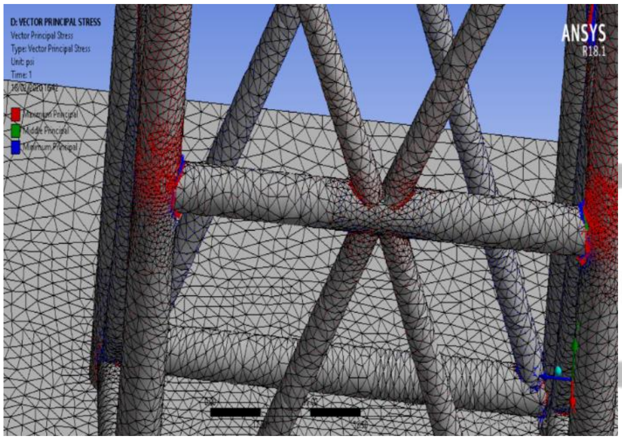

Fig. 6b The Vector Principal stress

In the above picture, is representing in mesh color the maximum and the minimum value of the stress acting in the pillars.

3.5 BIAXIALITY INDICATION

The biaxial indication shows the stress state. However, the biaxial stress act only on 2 directions in this case it acts on X-axis and Y-axis while the Z-axis is being assumed to be zero and these types of stress arises from analysis on pressure vessels, beam and offshore platform structures.

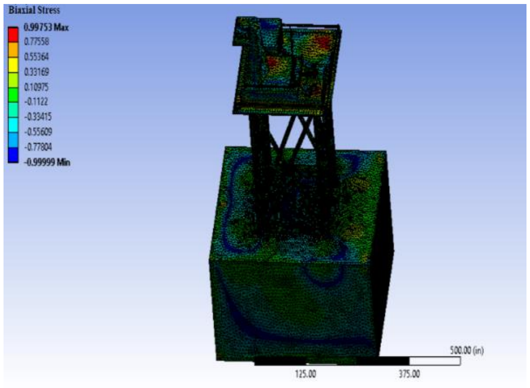

Fig.7a The state of stress on the entire platform

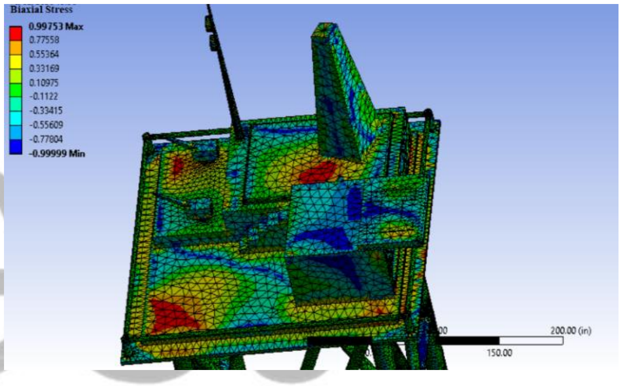

Fig.7b The state of stress on the entire platform

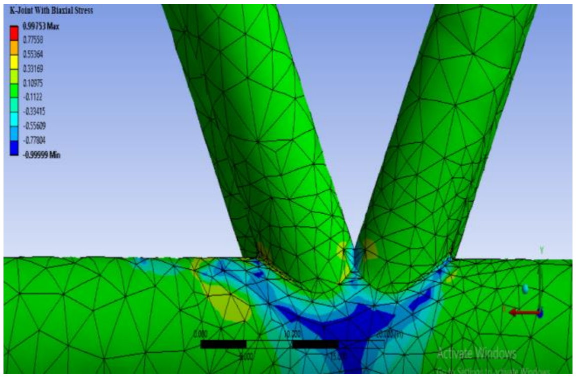

Fig..8 K-Joint with Biaxial Stress

3.6 THE CRACK LENGTH

In the figure below present the crack length, it is observed that there is a maximum crack length of 0.133inh and a minimum of -0.005inch from the simulation. However, the crack is located at the welded joint between the Chord and the Brace, and it is a semi-elliptical crack.

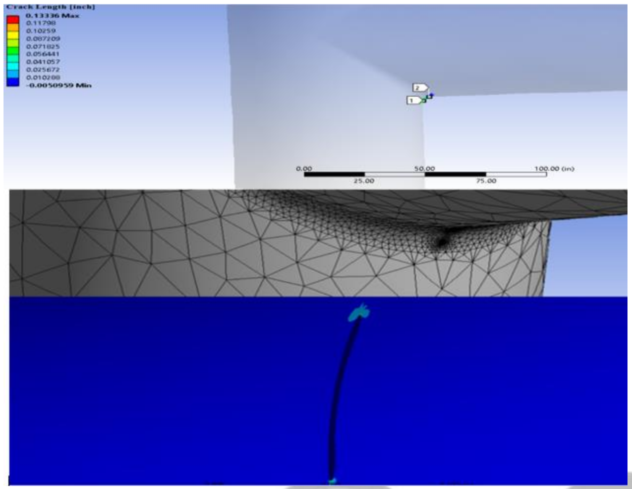

Fig. 9 Simulated Crack Lengths.

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The negative value of the crack means that it begins from inside of the seam weld and the positive value, represents the length of the surface crack.

CONCLUSION

The fact that offshore structures are exposed to environmental loading, the wave loading action is the main source of offshore potential fatigue cracking.

However, there are some other sources of cyclic loading which can also contribute to the fatigue damage and it should also be considered. Wind and gravity loads are also important to take into consideration when designing an offshore jacket platform.

Therefore, a crack length calculation for the k-joint analyze was perform and observed that the total crack length of the steel jacket offshore platform is 0.129inch and to failure, which implies that the platform is safe and it will take for crack to propagate. After the above number of cycles, there is need to take measures to mitigate the increasing crack.

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